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The Fixation of Atmospheric Nitrogen

Walter Savage Landis

The Fixation of Atmospheric Nitrogen*

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I assume more or less familiarity with the use of nitrogen in one or more of its various combinations, for even a partial catalog of the most common commercial nitrogen compounds would read like a few pages out of *Olsen's Chemical Annual* or the *Chemiker Kalender*. I will not even give statistics of consumption of the nitrogen compounds, because the very complex nature of these statistics would make them difficult of comprehension if merely read from prepared tables. I need but say that in tonnage alone the nitrogen compounds stand well at the head of the list of the world's trade in heavy chemicals, nitrate of soda and sulphate of ammonia being produced in 1913, to the value of $200,000,000.

Chilian Saltpeter and Coke-Oven Ammonia

Not including atmospheric nitrogen, whose utilization is yet in its infancy, we are practically dependent for our supply of this valuable element upon the nitrate deposits of Chile and upon its recovery as a by-product from our fuels. The Chilian deposits have been so frequently and fully described elsewhere that we can omit reference to the same here. The end of this source of supply is, however, in sight, and it will only be a few years until Chilian nitrate will pass into history along with our anthracite coal and the Saxon silver-lead ores.

The recovery of ammonia as a by-product from fuel is entirely different, for in the coke oven and the gas producer we will have an ever-increasing source of this element for many centuries to come, from which it is obtained in one of its most valuable forms of combination, ammonia. This source of supply is, however, somewhat unsatisfactory, inasmuch as it is wholly a by-product of the coal distillation industry, a ton of coal yielding only 5 to 6 lb. of ammonia, and by-products as a source of primary supply have many limitations. This is well illustrated by the present status in Germany, from which country I have lately returned. There is in that country just now a considerable shortage of nitrogenous fertilizer because the Government has confiscated all stores of nitrate for military purposes. (The fertilizer industry there consumes about 800,000 tons of nitrate per year.) The coke ovens which we should expect would normally come to the rescue in such a crisis are, however, largely closed. Ammonium sulphate production is, therefore, correspondingly decreased just at a time when agriculture needs it most, and its lack is felt acutely. Since my return I have learned that the use of coal has been prohibited in Germany in order to force the use of coke and thus increase the supply of ammonia and tar.

We came very near having the same conditions arising in this country, for were the farmer in position to take his normal fertilizer requirements there would be a great sulphate shortage, as our own industrial depression has closed down many of our coke ovens, and we would have no ready means of meeting even a normal demand for sulphate. We thus see the disadvantage of a by-product source of such an important element as nitrogen, and we understand why inventors have turned so actively to finding a substitute for the Chilian nitrate and the coke-oven ammonia.

Fixation of Atmospheric Nitrogen

Naturally the inexhaustible store of atmospheric nitrogen has presented itself most prominently in this search for a new source. Neglecting the many proposals which have merely wasted much paper and ink in describing impossible methods for the fixation of our atmospheric nitrogen, I am going to devote my attention solely to the successful and at the present time commercially developed efforts in this field.

We can classify these successful attempts into three groups:

1. Direct synthesis of nitrogen and hydrogen to ammonia.
2. Combustion of nitrogen and oxygen in the electric arc.
3. Combination of nitrogen with metals or carbides.

Synthetic Ammonia

The only commercial process to-day, belonging to group 1, is the so-called Haber process. Dr. Bernthsen (this journal, Vol. X, p. 637, 1912) described this process at the Eighth International Congress of Applied Chemistry, and exhibited a small working model of the apparatus. I am sorry that I can add but little to the technical information he there presented, but the owners of this process have maintained the greatest secrecy with respect to its commercial development, and but little is known regarding the details in the commercial world.

As you will recall, this process consists in passing a mixture of three volumes of hydrogen and one volume of nitrogen, at a pressure of upward of 150 atmospheres over a suitable catalyzer operating at a temperature of some 500-700 deg. C. A single passage of this mixture through the apparatus causes a transformation of 2 per cent to 6 per cent of the nitrogen to ammonia, which is recovered from the apparatus by condensation and the rest of the uncombined gases are again returned to the cycle.

Too much honor cannot be shown the courageous chemists who have succeeded in placing this process on a commercial working basis. The difficulties seemed almost insurmountable. The catalyzer, which has taken various forms and compounds, principally metals and carbides, poisons very readily, and, therefore, extreme care must be taken in the purification of the gases. Purity which the average chemist would classify as C. P. finds no place in this industry, as that would lack almost as much of meeting the requirements of the process as the use of crude chemicals in the analytical laboratory. It took years of work to find a suitable metallic container for the high-pressure gas mixture, because of the permeability of most ordinary materials. However, most of these difficulties have been overcome, and I have been reliably informed that the Badische plant at Oppau supplied its allotted quota of sulphate to the German Sulphate Sales Company last year, but I greatly doubt that they did it at a profit if it was made from synthetically produced ammonia, with sulphate prices as low as they were in the early part of 1914.

This process as ordinarily understood is not supposed to involve the use of any considerable quantity of electric power (which is not quite true), but does require a large amount of highly skilled labor, for the units are small and complicated. This particularly suits it to the Rhine location, but renders its value in the United States rather questionable. I personally cannot see a future

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for its operation under American conditions, particularly in view of the competition of the much cheaper cyanamid process which furnishes the same end product—ammonia.

At Oppau the Badische company must dispose of large quantities of waste sulphuric acid and have a by-product hydrogen, hence local conditions favor the Haber process above all others.

Direct Combination of the Nitrogen and Oxygen in the Air

The second group of processes embraces those oxidizing the nitrogen of the atmosphere in the electric arc. It is well known that when air is heated to temperatures of about 1800 deg. C., the nitrogen oxidizes to NO and remains, on rapid cooling, in that form. At that temperature, however, the reaction velocity is very low and commercial working requires that temperatures of above 3000 deg. C. be used, at which temperature the reaction velocity becomes quite considerable.

Three types of apparatus are in commercial use for performing this reaction:

1. The drum furnace with disk arc, of Birkeland and Eyde.
2. The long tube furnace with spiral arc, of Schönherr.
3. The narrow furnace with fan-shaped arc, of Pauling.

There are numerous other proposed types of apparatus which are claimed to be superior to the above, as reference to patent literature in particular will show, but the above listed three furnaces are the only ones in actual every-day operation.

The product obtained by passing air through the arc of any of these furnaces consists of a highly heated gas containing from 1 to 2 volume per cent of nitric oxide. On cooling down to temperatures of approximately 600 deg. C., this nitric oxide unites with free oxygen to form nitrogen peroxide, NO_2; on further cooling of this nitrogen peroxide to below 140 deg. C., it polymerizes to N_2O_4. When brought into contact with water and oxygen this reacts forming a mixture of equal molecular parts of nitric and nitrous acids. By subjecting the nitrous acid to further action of the peroxide this is also changed to nitric acid with the liberation of nitric oxide, which again passes through the cycle.

Thus by suitable cooling of the nitric oxide in the presence of air and water one ultimately attains a product which consists almost quantitatively of nitric acid, and actual operating results of the large furnace plants have shown a steady recovery of about 90 per cent of the nitrogen oxides in the form of nitric acid or nitrate salts, the remainder being received as nitrite or not absorbed.

In general the handling of the nitrose gases from the arc furnaces is now well standardized, and the design of a condensation plant is almost as well understood to-day as that of a sulphuric acid plant. After passing the various systems of cooling apparatus, consisting of steam boilers, evaporators, etc., the gases enter aluminium condensers where the temperature is reduced to approximately 100 deg. C. They then enter a preliminary oxidation chamber so proportioned that they remain in the same at least one and one-half minutes before leaving, where the preliminary oxidation to peroxide takes place. The gases next pass into a series of four or five stoneware or granite towers where they are washed with water by a counter current system, remaining in the tower system for from three to five minutes. Of the nitrogen oxidized 90 per cent is here condensed as nitric acid, the most concentrated acid being obtained in the first tower, and averaging from 30 to 35 per cent HNO_3. After passing these condensing towers the gases usually enter a final tower fed with caustic soda liquor, where a further 3 to 5 per cent of the oxidized nitrogen is recovered as sodium nitrite. The remaining 5 per cent passes out into the air unabsorbed.

As above mentioned, these towers deliver a 30 to 35 per cent nitric acid; this can be further concentrated to 50 per cent nitric acid, using the heat of the hot gases issuing from the arc furnace to perform the necessary evaporation. It is not possible to carry this evaporation much above 50 per cent for economical reasons, and where higher concentration of nitric acid is demanded special complicated concentration processes must be employed.

Dilute nitric acid, as obtained from the towers, finds little use in industrial processes, and it is difficult to transport. Most of the nitric acid plants, therefore, either concentrate it to 96 per cent acid by special means, or convert it into calcium nitrate for fertilizer use, or into ammonium nitrate for explosive purposes. In the latter case most of the ammonia used to-day in the nitric acid plants, operating on the arc system, is obtained from cyanamid.

It is quite probable that calcium nitrate will soon disappear from the fertilizer market as it certainly cannot be sold at a profit in competition with Chilian nitrate or ammonium sulphate even when the latter is made from cyanamid.

As we shall see later these arc processes require enormous quantities of cheap electric energy, and must be located near such power centers. We have no cheap power in the United States, and there is no immediate prospect of our having an arc process in continuous large-scale operation within our borders. Our Western powers are far from markets and transportation of the nitric acid as such to the East is almost out of the question.

Cyanamid Process

The third group of processes, as catalogued in my introduction, embraces fixing nitrogen by metals or carbides, and has reached its highest development in the cyanamid process, which last year produced throughout the world in the fourteen factories at present in operation, some 300,000 tons of material, carrying over 20 per cent nitrogen.

The inventors of the cyanamid process originally attempted the synthesis of cyanides by subjecting barium carbide to the action of nitrogen, which, as is well known, forms barium cyanide. On attempting to use the cheaper calcium carbide in place of barium carbide, Professors Frank and Caro found that instead of obtaining cyanide they obtained a new material, which proved to be calcium cyanamid. It was later found that this material could be utilized directly in agriculture, and from this discovery has grown the enormous cyanamid industry which has proven itself to be the cheapest method of fixing atmospheric nitrogen at present in existence.

Reference to the literature existing upon the manufacture of cyanamid seems to lead one to suppose that it is a comparatively simple matter to carry out the reaction so frequently written:

$$CaC_2 + N_2 = CaCN_2 + C.$$

This might be true to a limited extent were this the only reaction that we chemists at Niagara had to contend with, but I can merely say to you that even this reaction itself it so complicated that while it is well known that it is a reversible one, no one has yet succeeded in correctly establishing its equilibrium constants. A laboratory study of this reaction has been

carried out both in this country by Prof. M. de Kay Thompson (this journal, Vol. VIII, p. 617 and 687, 1910), and abroad by Professor Haber, but neither of them has succeeded in mastering the same, because of the peculiar difficulties that arise in a study of it.

Naturally if the highly skilled chemical laboratories have met with these difficulties, we can assume that practice runs against a few of them itself. But aside from the fundamental absorption reaction, as written above, there are a number of other complications that arise in this industry which we have to meet with in our every-day work, and which I shall call to your attention to show that the actual carrying out of the cyanamid process requires something more than writing the reaction on a piece of paper.

The fertilizer industry, into which most of our material at present goes, is a rather peculiar one, and probably has more peculiar fads and precedents than almost any other highly developed industry in the country. Naturally to sell to fertilizer men material we must take into account all of the peculiarities of the industry, and we must satisfy them—a fact which further complicates the cyanamid industry itself. But it may be assumed that inasmuch as cyanamid is being produced and sold at the rate previously mentioned we have succeeded somewhat in meeting these fancies.

The first stage of the cyanamid process involves the production of calcium carbide. To produce day after day a high-grade calcium carbide that meets the peculiar requirements of the cyanamid industry is quite an art in itself. There are no journeymen carbide workmen in our country, and we had to start out and develop our own furnaces and methods of operation. We had to seek sources of raw materials for this manufacture, which are quite different even from those which meet the requirements of the manufacture of lighting carbide, and we have to operate our furnaces in a certain peculiar way in order to combine these raw materials into a product of such structure and grade that we can make cyanamid out of it successfully. As may be recalled, Moissan in his early work found that he could not nitrify certain kinds of carbide, showing that there are conditions existing in our carbide manufacture that are different from those in the manufacture of lighting carbide.

Our next great problem was to grind this special grade of calcium carbide so that it passes a hundred-mesh screen. Naturally this must be done without slacking the carbide, as hydrated lime does not make good cyanamid. Now 100-mesh carbide dust is almost as explosive as low-grade dynamite when exposed to the atmosphere on a damp day, or thrown out on damp ground, so that it is quite some little problem of itself to grind this carbide to the required degree of fineness and have a mill left at the end of the day's run.

Next comes the production of nitrogen. It is a comparatively simple matter for the chemist to make a few cubic centimeters of high-grade nitrogen in his laboratory, but if one were to call upon him for 2,000,000 cu. ft. of a practically pure nitrogen per day, such as we make at Niagara, he would probably have to do considerable research to find out just how this enormous quantity of such high-grade material could be made. In the early days of the cyanamid process, when the Ni-

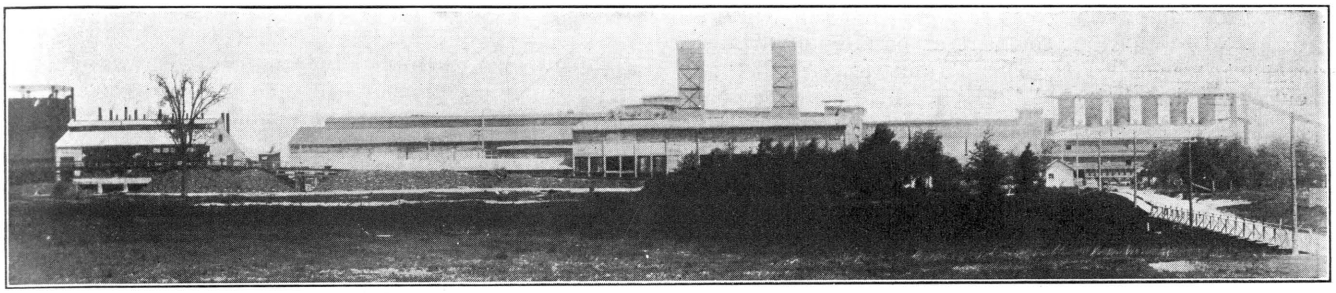


FIG. 1—AMERICAN CYANAMID COMPANY'S WORKS AT NIAGARA FALLS—LIME PLANT AT THE EXTREME RIGHT; COAL-GAS PLANT AT THE EXTREME LEFT; CARBIDE AND CYANAMID BUILDINGS IN CENTER

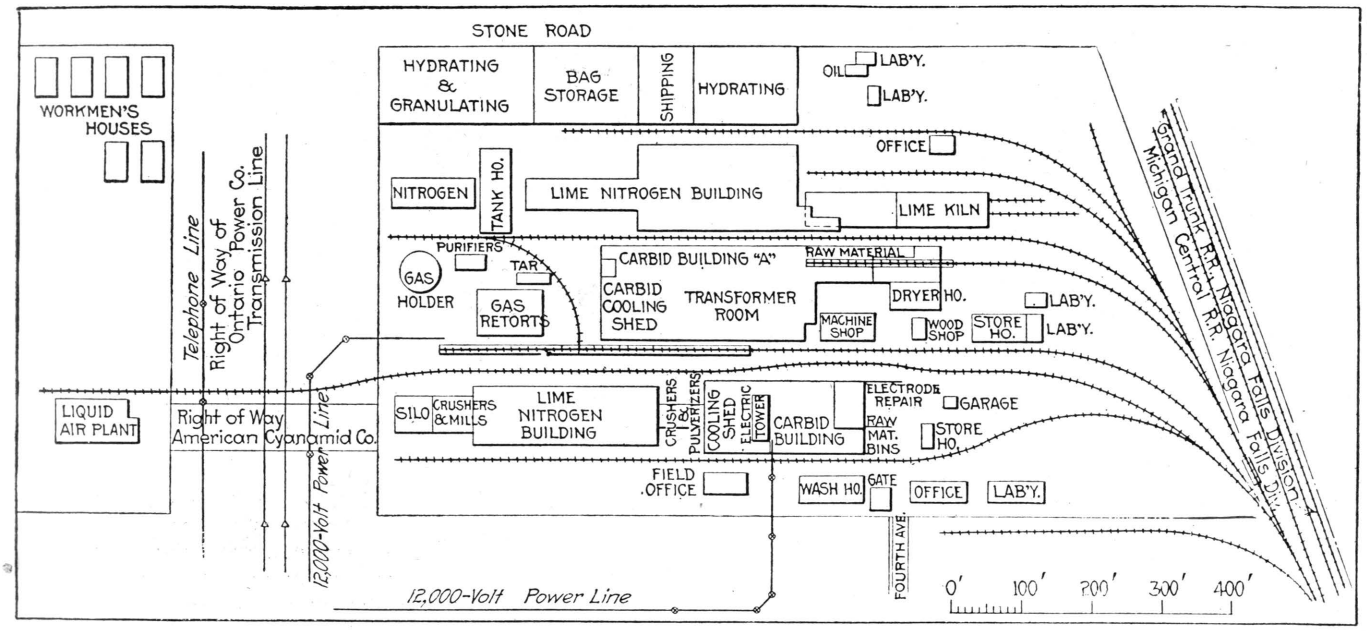


FIG. 2—PLAN OF AMERICAN CYANAMID COMPANY'S WORKS AT NIAGARA FALLS, ONTARIO

agara plant started, liquid air machinery was in a rather backward state of development, and we were forced to make our nitrogen by passing air over copper. The original plant was later enlarged. It was a long step from the combustion tube of the chemical laboratory to our present plant using retorts containing 5 tons of copper mass, but the problem has been successfully solved, and the new plant has been in operation with a minimum of trouble for some years.

In the early days of the industry at Niagara we could draw upon natural gas for reducing our copper oxide, so as to revivify it, but this gas supply has since failed and we were forced to put up our own coal gas plant. Even this coal gas plant is not a standard one, inasmuch as we are coking coal, not only for the production of gas, but also to furnish the coke for our carbide furnaces. We are running at temperatures in our retorts and obtaining qualities of coke and gas that the average city gas plant would not consider as possible of attainment, and it was only after considerable experiment that we ourselves demonstrated that our theories were correct in this respect and succeeded in finding gas engineers liberal-minded enough to incorporate our ideas into a working plant.

Eventually we had to install purification apparatus for taking out the impurities in the nitrogen, as it came from the copper retorts, and have equipped ourselves with soda towers for removal of carbon dioxide, refrigeration plants for drying, lime tanks for purification, etc., and have even developed this plant so highly that we have included a causticizing plant for recovery of our spent alkali.

After the development of the liquid air machinery, both in the way of capacity and reliability, the problem of producing pure nitrogen was much simplified, and our latest addition at Niagara includes what was probably the largest liquid air plant in the world at the time it was built, a year ago. This plant alone throws to waste almost 30 gal. of liquid air an hour, just to keep the apparatus flushed out and in good working order, not to speak of the thousands of cubic feet of rich oxygen-nitrogen mixture.

After one has overcome the difficulties in the production of a proper grade of nitrogen and of carbide, the next step is exposing these two to mutual reaction at a proper temperature, which is done in small individual ovens, holding from ½ to 2½ tons of carbide. The reaction itself is reversible, and particular precautions must be taken to always keep it running in the right direction until the carbide has all been nitrified. The physical and chemical conditions which must be met with in this part of our work are very complex.

The product removed from these ovens is a black, hard cake, which analyzes 22 per cent nitrogen and about 1 per cent un-nitrified carbide. This material, which we call "lime nitrogen," is next finely ground and stored in silos. The carbon set free in the reaction previously indicated is in the form of graphite, and it is not an easy proposition to find a satisfactory mill that will grind this material fine and at the same time not blow itself up from liberated acetylene derived from the presence of any uncombined carbide, or wear itself out grinding the lime nitrogen-graphite mixture. Extreme precautions are taken in this part of our operation, both in the mills themselves and in the elevating and conveying apparatus connected with them to avoid dangerous explosions, but I can truthfully say that in the years I have been connected with the company not a single injury has resulted from such explosions in our plant.

To prepare the lime nitrogen for agricultural purposes the finely ground material is partly hydrated to insure decomposition of the carbide it contains, and is then oiled to render it dustless, and stored in bulk, or packed immediately into sacks and shipped to the fertilizer mixer.

Calcium cyanamid tends to transform itself into a large number of organic compounds when subjected to the action of water, particularly at temperatures above normal, and, therefore, this hydration has proven an extremely complex problem, because we desire to avoid any such transformation, as agricultural experiments have shown that the calcium cyanamid in its unaltered form yields the best crop results.

Ammonia from Cyanamid

But agricultural uses are not the only purposes to which the cyanamid can be applied, as it is a very simple matter to convert the cyanamid into ammonia by the exothermic reaction

$$CaCN_2 + 3H_2O = 2NH_3 + CaCO_3.$$

If lime nitrogen is mixed in a slurry with water and subjected to the action of heat and high pressure, it is converted quantitatively into ammonia. In this country this use of cyanamid was not developed on a large scale outside our experimental laboratory until the beginning of this year, but while I was in Germany I saw in the yards of a big manufacturing concern there some sixty autoclaves, each capable of converting 10 tons of cyanamid into ammonia per day. This equipment was waiting railroad cars to move it out, and was in no sense experimental, because three similar plants have been in operation in Germany for at least three years. The cost of this transformation is hardly appreciable, and the purity of the product is quite high, requiring merely passing through a self-acting rectifying column for the removal of steam.

A New Ammonia-Phosphate Fertilizer

The ammonia so produced abroad is at present converted into a high-grade sulphate and a pure nitrate, and we are at work now in this country on producing a new fertilizer material, "ammophos," consisting largely of ammonium phosphate; my experimental laboratory at present working day and night trying to meet initial demands for this new material. Agricultural results the past season have been so phenomenal that our friends will not await the completion of a large plant for meeting the requirements, but have insisted on our converting our laboratories into a miniature factory.

Our product contains over 13 per cent NH_3 and 45-50 per cent P_2O_5, or over 60 per cent plant food, the bulk of the remainder being chemically combined water, and when mixed with the high-grade potash salts available will make a complete fertilizer some six times as concentrated as the average grades sold to-day.

Urea, Dicyandiamid, and Creatin from Cyanamid

It is also possible to transform cyanamid into urea, and I have made in my experimental laboratory a great deal of pure salt in a comparatively easy and simple manner.

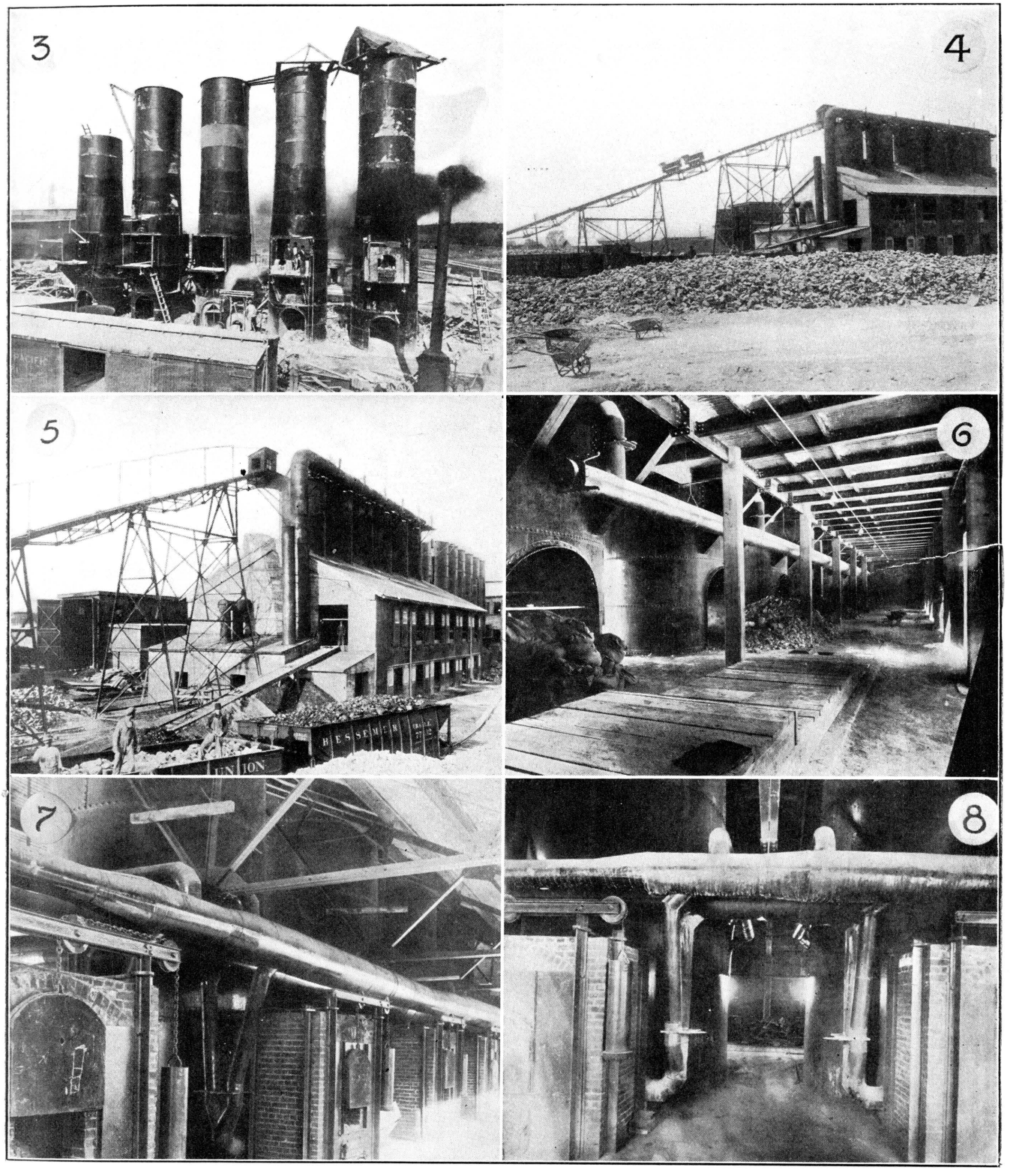
Similarly it can be converted into dicyandiamid by simple treatment with hot water. This material has been proposed for use as a deterrent in explosives, but which I think offers a much better field for transformation into the guanidines.

Such transformations of cyanamid abroad have received a great deal of attention, and there are numerous derivatives on the market. Just a few months ago I saw a sample of creatin which had been made in a chemical laboratory from cyanamid, and we feel that we in the industry are not very far from the synthetic production of foods when we can reach such a point in our chemical synthesis.

Cyanide from Cyanamid

When a special grade of cyanamid is melted down with a flux, such as common salt, it combines the free carbon present with the cyanamid radicle, forming cyanide. The resulting product of this fusion contains about 25 per cent of its weight in equivalent potassium cyanide; this crude form of cyanide dissolves very readily in water and filters rapidly from the insoluble, after which the solution is ready for metal extraction, or other uses to which cyanide in its dissolved form can be put.

Large scale experiments have been tried out in a number of the big cyanide plants scattered at various places throughout the world, and in every respect this material has shown an exactly equivalent value to the higher grade cyanides. The transformation of the cyanamid nitrogen into cyanide nitrogen is almost quantitative, and the fusion experiments can be carried out



FIGS. 3 TO 8—LIME PLANT OF AMERICAN CYANAMID COMPANY

Fig. 3: Kilns in course of construction with shells erected and fire-clay lining started. Fig. 4: Finished lime plant showing piping for induced draught and Eldred process. Fig. 5: Old lime plant with new addition, and railroad cars. Fig. 6: Lime discharge floor. Fig. 7: Firing floor with piping for Eldred process and counterweight arrangement for charging door. Fig. 8: Arrangement of the return CO_2 and hot-air pipes and damper control for Eldred process.

without difficulty and at a low cost. We have here, therefore, a crude form of cyanide which can be prepared very cheaply and which could be readily delivered to the consumer at a price approximately one-third under the present prices of the higher-grade cyanide.

Abroad this material has been made in large quantities and transformed into the pure cyanide running approximately 127 per cent potassium cyanide equivalent, but we believe that with proper propaganda work our own cyanide users would find the low-grade material quite acceptable, provided it could be delivered to them at a cost sufficiently low to enable them to perform the extra dissolving and filtering operation which it involves over the use of the present high-grade alkali cyanides.

Cyanamid for Case Hardening

Cyanamid itself forms an excellent case-hardening material, and we have prepared a number of mixtures which are in steady use at our plant for performing this operation upon various machine parts which we are using. It works extremely rapidly at very low temperatures, but we have not yet succeeded in overcoming certain fads in large scale use of this material, and it has not met with any general introduction. We found the case-hardener is more concerned with the color of his hardening powders than he is with the actual work they perform, and as the colors and odors of our cyanamid products are rather fast we have not found it interesting to us to meet some of these peculiarities of the case-hardening trade. While abroad I saw these case-hardening materials being prepared by the hundreds of tons for use in the manufacture of armament and war materials, and the small factory engaged in their production has been swamped with orders ever since its inception.

Comparison Between Different Processes for Fixation of Atmospheric Nitrogen

The arc processes have shown themselves capable of producing nitric acid or nitrates; cyanamid itself is an entirely different product, but it is quite easy to produce ammonia from it, and there has recently been evolved abroad a most successful method* of oxidizing this ammonia to nitric acid, so that in case of competition with the Birkeland-Eyde process we are not entirely limited to the fixation of nitrogen, but can furnish this nitrogen in exactly the same form that the arc processes can, and at considerably less cost.

The raw materials for cyanamid are cheap—coke, limestone, air. We use only one-fifth the electrical power that the arc processes do per unit of nitrogen fixed in the form of cyanamid, respectively ammonia, and by the addition of a very small percentage more power we can convert our cyanamid into nitric acid. We require about the same quantity of labor to fix a unit of nitrogen in cyanamid as the arc process does in nitric acid, but since there is only a small fraction more labor used to transform cyanamid nitrogen into nitric acid we do not feel this is a great handicap when one considers our smaller power consumption. On the American continent, where water power is so expensive and so scarce, this difference readily offsets the additional labor necessary to make nitric acid from cyanamid.

Further, our cyanamid is easily transported and can be changed to ammonia or nitric acid at the end of its journey at the expenditure of a very small amount of steam and labor, so that we have the additional advantage in transportability of stable raw material, and subsequent conversion at the point of direct use. These commercial transformation units are small, and can be set up to supply even small amounts of ammonia or acid in a quite cheap and efficient plant. Practically all sulphuric acid plants in Germany have installed them since nitrate has disappeared from the trade.

There is no comparison between the initial investment required for a cyanamid plant and for an arc plant if one will include power development. The cyanamid plant, per unit of nitrogen fixed, requires an investment of only about one-quarter that required by the arc process, and for a cyanamid-ammonia plant about one-half that required by the Haber process. Even the combination of the cyanamid-ammonia-nitric acid process requires an investment of only one-third to one-half that for the arc process. In each case we are assuming exactly the same quantity of fixed nitrogen in the forms above designated.

Where electrical power is expensive, as in the United States, there is no question regarding the superiority of the cyanamid process for the fixing of atmospheric nitrogen, particularly for fertilizer purposes, and we eventually hope that the future development of our nitric acid process will enable us to compete in every line of nitrogen compounds with all other competitive sources.

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The Niagara Falls Plant of the American Cyanamid Co.

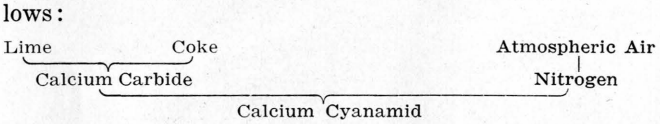
Mr. Landis illustrated his paper by a series of very interesting moving pictures, showing the most important steps in cyanamid manufacture at Niagara Falls.

As a substitute for the movies we give some representative views. As the Niagara Falls plant of the American Cyanamid Company comprises a 12-kiln lime plant, 25,000 horsepower of calcium carbide furnaces, a liquid-air plant which was the largest in the world a year ago, a gas plant of sufficient size to serve an average town of 25,000 inhabitants, a nitrogen retort plant, an ammonia refrigeration plant, a causticizing plant, a nitrification plant, a hydration plant, and innumerable crushers, mills, silos and feeding machinery, we cannot do more than give illustrations of some departments, chiefly the gas plant and the lime plant.

Fig. 1 gives a view of the works of the American Cyanamid Co. at Niagara Falls, Ontario, showing the lime plant at the extreme right, the coal gas plant at the extreme left, and the carbide and cyanamid plant in the center. A diagrammatical plan of the arrangement of the whole works is given in Fig. 2, which is reproduced from *Engineering News* of January 7, 1915.

The plant was started in 1909 with an annual output of 12,000 tons of cyanamid. The plant was enlarged in 1913 to an annual output of 32,000 tons, and in 1914 again enlarged so that the output is now 64,000 tons.

The whole operation may be concisely sketched as follows:



Concerning the production of the cyanamid from carbide and nitrogen nothing need be added here to Mr. Landis' paper.

The manufacture of calcium carbide is carried out in continuous operation in eight 20-ton, 3000-hp three-phase electric furnaces, each with three large carbon electrodes at the top. The charging platform for the furnaces is on a level with the top of the furnaces. The transformers are placed below the charging platform close to the furnaces, so as to require only very short connections between furnace and transformer.

*See, for instance, this journal, vol. 11, page 438 and 476, 1913.

Lime Plant.

The lime is burnt in the lime plant which was designed by the Improved Equipment Company of New York City, to whom we are indebted for the photographs reproduced in Figs. 2 to 8. The lime plant consists of twelve Doherty-Eldred lime kilns, equipped with the Eldred process and operated with induced draught. The first installation comprised six kilns, and six more were erected last year.

Fig. 3 shows the kilns in course of construction; the kiln shells have been erected and the fire-clay lining has been started. Fig. 4 is a view of the finished lime plant and shows the piping for induced draught and Eldred process. Fig. 5 is a view of the old lime plant with the new addition in course of erection, and shows the limestone being brought to the plant in cars. Fig. 6 is a picture of the lime discharge floor, Fig. 7 a picture of the furnace or firing floor with the piping for

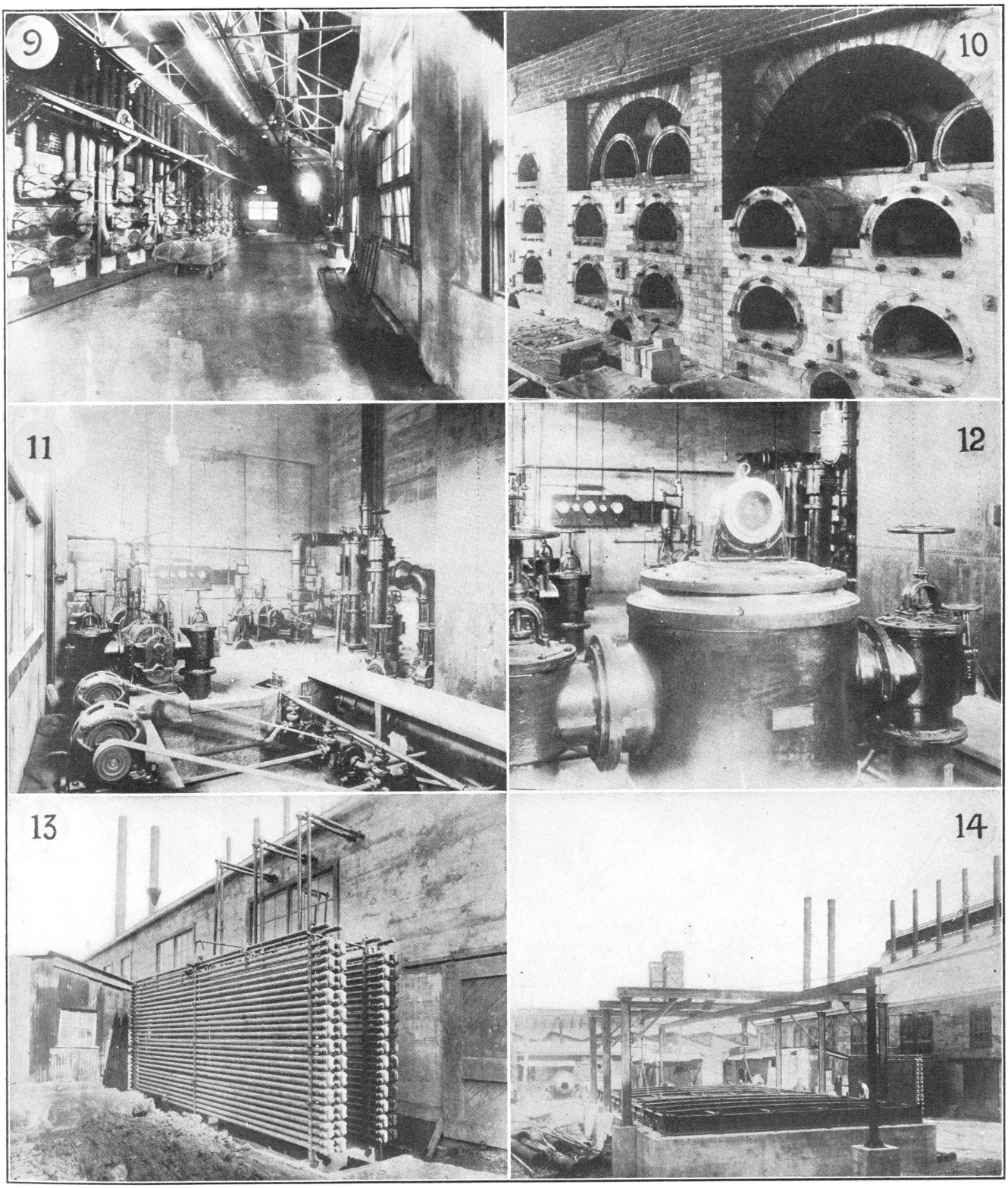


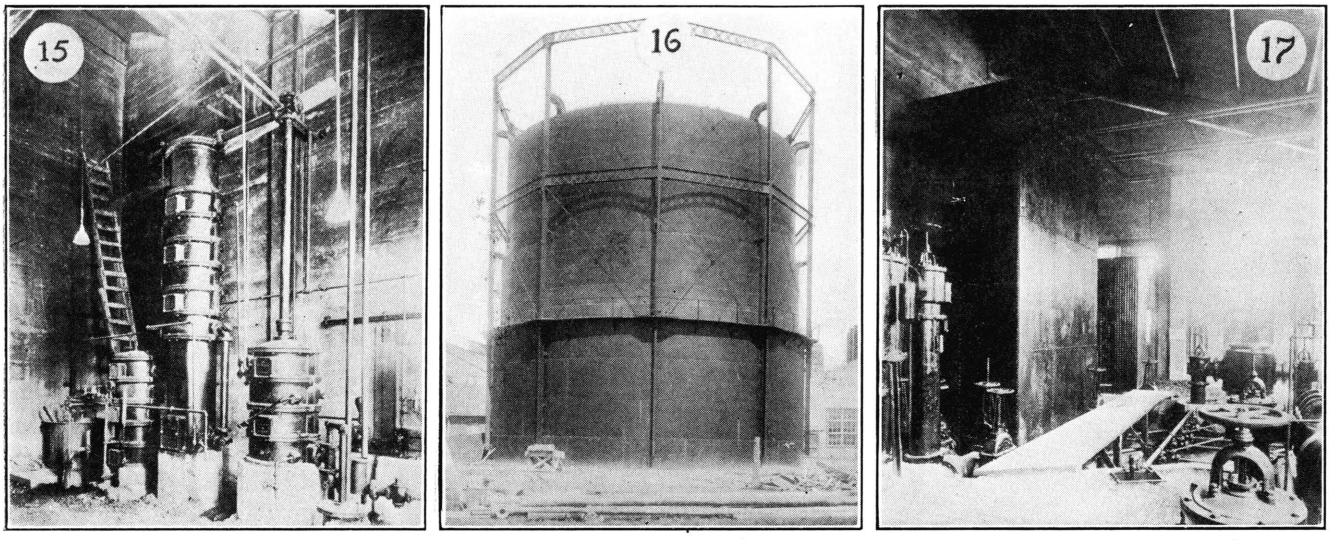
FIG. 9 TO 14—COAL GAS PLANT OF AMERICAN CYANAMID COMPANY

Fig. 9: Charging floor of retort house with conveyor system and coal buggy. Fig. 10: Manner of laying up the sectional silica retorts and settings. Fig. 11: Machinery room with Doherty washer cooler and centrifugal pump. Fig. 12: Rotary meter. Fig. 13: Side view of cooling coils of Doherty washer cooler. Fig. 14: End view of concrete purifying boxes.

the Eldred process and counterweight arrangement of the charging door, while Fig. 8 shows the arrangement of the return CO_2 and hot-air pipes and the damper control for the Eldred process.

The Eldred process and its applications to lime kilns was described very fully in an article by Mr. Carleton Ellis in our Vol. II, p. 495 (1904). The exhaust gas from the kilns is drawn by an exhauster from the top of the stacks and part of it is used as a "diluent" for the air in the fire boxes to get correct conditions of combustion. The balance of the exhaust gas is led to the waste stack.

The coke for the carbide manufacture is partly bought as such and the balance comes from the gas plant to be described later.



FIGS. 15 TO 17—COAL-GAS PLANT OF AMERICAN CYANAMID COMPANY

Fig. 15: Ammonia still. Fig. 16: Gas holder of 100,000 cubic feet capacity. Fig. 17: Doherty washer cooler

Nitrogen from Air.

As explained in Mr. Landis' paper the nitrogen (needed for the reaction with carbide to form cyanamid) must first be separated from the oxygen in the atmospheric air. Two different processes are being used for this purpose at Niagara.

The newer method, installed for the latest extension of the plant last year, uses liquid air produced by the Claude process. The oxygen is separated from the nitrogen by fractional distillation of the liquid air.

The older method used is the so-called copper sponge method, in which retorts filled with copper sponge are employed. When a series of these retorts is heated and air is blown through the copper sponge, the oxygen of the air combines with the copper, forming cupric oxide and leaving the nitrogen free. The flow of air is then diverted to a second series of heated retorts, also containing copper sponge, while coal gas is passed through the first series of retorts so as to reduce the cupric oxide to copper sponge. This is then used again for combining with the oxygen in a fresh amount of air and setting the nitrogen free, and so on. The process is therefore cyclic.

Coal Gas Plant

From the foregoing description it will be seen that the coal gas plant serves a double purpose. It provides coke for the carbide manufacture, and it provides the coal gas for the reduction of cupric oxide in the separation of nitrogen gas from atmospheric air.

The coal-gas plant has a capacity of 500,000 cubic feet per 24 hours. As Mr. Landis explains in his paper above, the standard coal gas process is not used; the retort benches are run very hot to produce a gas rich in hydrogen and coke low in volatile matter. They "are running at temperatures in the retorts and obtaining qualities of coke and gas that the average city gas plant would not consider as possible of attainment, and it is only after considerable experiment that we ourselves demonstrated that our theories were correct in this respect and succeeded in finding gas engineers liberal-minded enough to incorporate our ideas into a working plant."

The coal gas plant was installed by the Improved Equipment Company of New York City, to whom we are again obliged for the photographs from which the accompanying illustrations were made. There are seven benches equipped with the Doherty bench fuel economizer and sectional silica retorts and settings.

Fig. 9 shows the charging floor of the retort house with conveyor system and coal buggy, while Fig. 10 illustrates the manner of laying up the sectional silica retorts and settings. Fig. 11 is a view of the machinery room with Doherty washer cooler and centrifugal pump. Fig. 12 shows the rotary meter, Fig. 13 is a side view of the cooling coils of the Doherty washer cooler, and Fig. 14 an end view of the concrete purifying boxes showing covers.

Fig. 15 shows the ammonia still, Fig. 16 the gas holder of 100,000 cubic feet capacity, and Fig. 17 the Doherty washer cooler.

Before concluding this article, attention should be called to an admirable paper by Mr. Frank S. Washburn, president of the American Cyanamid Company, which was presented last month at a joint meeting of the American Institute of Electrical Engineers and the New York section of the American Electrochemical Society, and will come up for discussion again at the annual convention of the American Electrochemical Society at Atlantic City in April. It will be published in full in our next issue. An abstract of this paper, together with an account of another excellent paper, by Mr. Summers, on the general situation in the fixation of atmospheric nitrogen, will be found on page 241 of the present issue.